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Interactive comment on "Impact of impurities and cryoconite on the optical properties of the Morteratsch glacier (Swiss Alps)" *by* Biagio Di Mauro et al.

Anonymous Referee #2

Received and published: 26 June 2017

Dear all,

This paper aims to combine field and satellite reflectance measurements with laboratory analyses of ice and cryoconite samples in order to map various impurities over a Swiss glacier. This is a worthy research aim, and the authors have undoubtedly produced a valuable dataset that will be relevant for future method development in impurity mapping. The paper is generally clearly written, its purpose is well articulated and the subject matter is appropriate for The Cryosphere. Ultimately, I would be pleased to see a version of this paper published.

There are, however, some issues that the authors ought to address prior to publication:

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Discussion paper

1. More details are required regarding the measurement protocol used to obtain spectral reflectance. What was the viewing angle? How was the fibre optic levelled? What was the footprint size of each measurement? Were the sample surfaces flat? The maximum clean ice visible reflectance in Fig.2 exceeded 1.3 – does this indicate that an oblique viewing angle or sloping surface caused the measurement to be near the forward scattering peak? How does the measurement angle compare with that of the Hyperion satellite?

2. I have some questions regarding the Snow Darkening Index (SDI). This measure is a ratio of blue and green reflectance values where more positive SDI is interpreted as high impurity load and vice versa. However, wet cryoconite has a near-flat spectrum across the blue and green wavelengths and will therefore have a low or negative SDI despite being very dark. In this case, the SDI cannot reliably distinguish between very clean and very dirty snow/ice. This is illustrated in Fig 2. Similarly, in Figure 2B the SDI would be lower for the wet cryoconite than the dry cryoconite despite it being much darker. Wouldn't the index also change as the snow or ice grains evolve, even when impurity loading remains constant simply because grain evolution preferentially alters reflectance in red-NIR wavelengths?

3. I also wonder about the use of SDI as a measure of mineral dust loading, compared to total impurities measured using Iimp? Mineral dusts, organic carbon, living algae, black carbon and mineral dusts all depress reflectance in the visible wavelengths and would all have similar effects on the SDI. Perhaps I have misunderstood, but it seems that SDI and Iimp are only arbitrarily different metrics. Presumably the different wavelengths lead to the metric having different sensitivities, but is there a meaningful difference in what they represent physically?

4. Reflectance across (most of) the visible wavelengths was integrated to provide albedo. However, integrating only the visible wavelengths omits a significant fraction of the total solar radiation that is crucial for the surface energy balance with the effect of exaggerating the albedo lowering effect of impurities. Albedo is also hemispheric.

Since ice is strongly forward scattering, large errors can result from assuming nadir reflectance can be integrated over the entire hemisphere without anisotropy correction. Was this accounted for in the analysis? If so, how? If not, the albedo discussion needs to be removed or heavily caveated.

5. I also agree with Reviewer 1 that intrinsic albedo reducing processes could influence the interpretation of the presented spectral data.

6. The albedo/spectral reflectance of cryoconite on the laboratory is likely to be very different to cryoconite in nature, especially when contained within cryoconite holes. Not only are the hole floors and walls made of ice with certain optical properties, the cryoconite material is usually submerged beneath a layer of water. This introduces specular reflection from the water surface, multiple reflections between hole walls and hides the cryoconite from light arriving from off-nadir angles. For cryoconite out of holes, its albedo influence will vary greatly depending upon the optical properties of the ice beneath it and how wet it is. For these reasons, care should be taken when inferring cryoconite's enhanced albedo-lowering effect relative to moraine sediment (page 10).

Specific Comments

Page 3, line 29: In what window around midday? Did you use midday or solar noon?

Page 4, line 14: Shouldn't they be normalised for mass, not concentration?

Page 6 line 29: These are also the wavelengths where both the incoming solar irradiance and snow and ice albedo peak. Are you confident the discrepancy does not lead to significant error?

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